STRUCTURAL COUNTERMEASURE STUDY ON OBLIQUE OFFSET FRONTAL IMPACT

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ABSTRACT

National Highway Traffic Administration (NHTSA) has been investigating an oblique offset frontal impact test. This project evaluates test and simulation results to determine structural changes to reduce occupant compartment intrusion. Review of test results indicated that mid-size Sedans and Pickup trucks showed higher structural intrusions and higher passenger compartment decelerations. Existing Computer Aided Engineering (CAE) models for a mid-size Sedan and Pickup truck were used to evaluate structural changes and the corresponding cost impact to improve performance in the oblique offset test condition. This paper describes the CAE study carried out to study structural reinforcement countermeasures for both the driver and passenger sides of the vehicle in left- and right-side oblique offset frontal impacts. This paper presents the structural mass changes due to reinforcement countermeasures and the cost impact.

INTRODUCTION

The objective of this research was to demonstrate necessary changes to a vehicle's structure and their associated cost in order to reduce the occupant compartment intrusion from NHTSA's oblique offset frontal crash condition. The finite element (FE) models of vehicle to be studied had to meet the structural intrusion requirements for a "Good" or "Acceptable" structural rating in the IIHS small overlap test, "Good" rating in IIHS moderate overlap test rating. The mentioned tests are as shown in Figure1.

The vehicle models chosen for this study were based on the availability of NHTSA oblique test results, and the availability of a good correlated CAE model. The CAE model should be modified with minimum effort to represent the vehicle for the NHTSA oblique test simulation. It also should represent a latest possible production year vehicle meeting NHTSA's 5-star rating as well as "Good" or "Acceptable" rating of IIHS small overlap frontal impact and "Good" rating of IIHS moderate overlap frontal impact.

Therefore, for the passenger car category, the chosen vehicle was the 2014 Honda Accord with "Good" IIHS ratings, 5-star NHTSA rating. The test results of 2014 Honda Accord were obtained from two NHTSA oblique tests.

For the pick-up category, the chosen vehicle was the 2014 Chevrolet Silverado 1500 with 5-star NHTSA ratings. In this case, the IIHS small overlap test results were not available when the model was developed. But IIHS has already conducted two small overlap tests on the 2016 Chevrolet Silverado, so the test results of 2016 Chevrolet Silverado 1500 were used for this study.

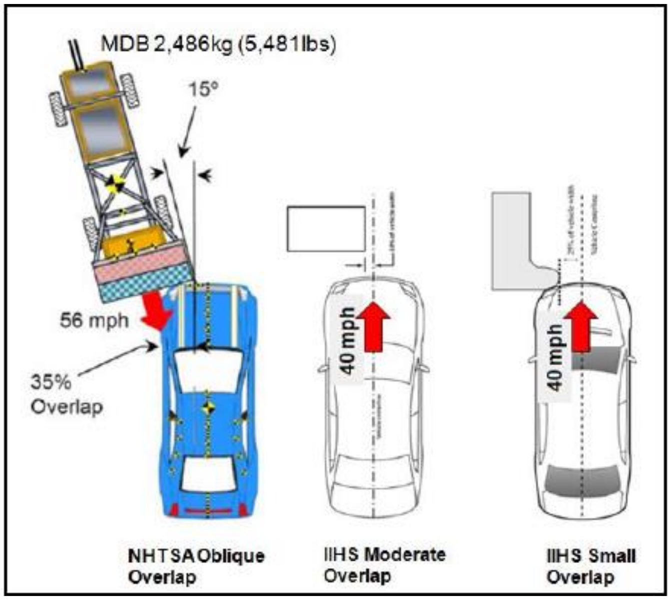


Figure 1. Vehicle Frontal Offset Tests.

During a high-speed crash event, the structural intrusions into the toe pan and dash panel are generally caused by hard contact between the intruding wheel and/or the engine/transmission assembly. In general, there are three methods applied to reduce structural intrusions. First is by absorbing as much energy as possible by the deforming structures. Second is by introducing failure points at key locations to deflect the intruding surfaces away from the critical zones on toe pan and dash panel and finally by reinforcing the passenger compartment by using high strength materials with optimized load paths.

This paper outlines the structural countermeasures undertaken to reduce the instructions by including these three methods. The detailed design of reinforcing components considered manufacturability, joining, and assembly into the vehicle design. Additionally, the cost impact of implementing the countermeasures was also studied.

The technical cost modeling (TCM) approach developed by Massachusetts Institute of Technology's Materials Systems Laboratory research was used in this research to estimate additional cost accrued due to the countermeasures. The TCM application allows consideration of the whole production process from part production, assembly, logistics and overhead cost.

COUNTERMEASURE STUDY

The countermeasure study included two vehicles Honda Accord 2014 and 2014 Chevrolet Silverado 1500. In each vehicle study, the FE model was developed first to obtain a baseline model compared to the corresponding crash tests. Upon validating the baseline model with acceptable correlation in terms of structural intrusions, it was used in the countermeasure development.

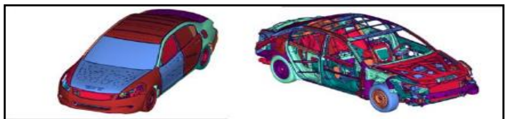
Passenger Car – 2014 Honda Accord

The full vehicle FE model of the 2012 Honda Accord which was developed and correlated for NHTSA's study [1] was updated to represent the 2014 MY Honda Accord. A few structural modifications going from 2012 to 2014 vehicle were undertaken by remodeling and updating the 2012 full vehicle model into 2014 full vehicle model. Necessary structural changes were obtained by white light scanning and CAD update of the 2014 vehicle parts accordingly. The details of updating 2012 Honda Accord full vehicle model is out of scope of this paper (it can be found in the NHTSA report [1]).

The updated FE model – 2014 Honda Accord full vehicle model is shown in Figure 2. The 2014 Honda Accord full vehicle model was setup for the following crash load cases.

1. NHTSA Oblique Offset Test (simulating left- and right-side frontal oblique offset)
2. Frontal NCAP Test

3. IIHS Moderate (40%) Frontal Offset Test
4. IIHS Small (25%) Overlap Front Test
5. Lateral NCAP Moving Deformable Barrier Test
6. Lateral NCAP Pole Test
7. IIHS Roof Crush Test
8. IIHS Lateral Moving Deformable Barrier Test



Number of Parts	1207
Number of nodes	2,124,917
Number of Shells	1,847,155
Number of Beams	659
Number of Solids	243,237
Total number of elements	2,091,327

Figure 2. 2014 Honda Accord CAE Model.

LS-DYNA simulations were run for each of the load cases. The simulation results were compared to the available test results. The review of the comparison between the FE results and test results concluded that, the overall correlation was acceptable to use the FE model for the oblique frontal impact requirements:

The details of baseline model development and FE results comparisons with test results can be found in [2]. The correlated FE model was used to identify suitable countermeasures design to reduce the occupant compartment intrusions. The countermeasures were based on observed body structure deformations when subjected to oblique impact on the driver and passenger sides. Higher intrusion values were mainly observed in the mid to lower section of the dash panel impacted by battery and brake booster assemblies on the driver side and by the transmission and engine block on the passenger side of the dash panel. Several CAE iterations were conducted to find the optimal set of structural changes. The recommended changes have to be fine-tuned in such a way that vehicle crash performance is not jeopardized for all other crash requirements, and also to make sure the design-packaging space for other vehicle systems is not violated.

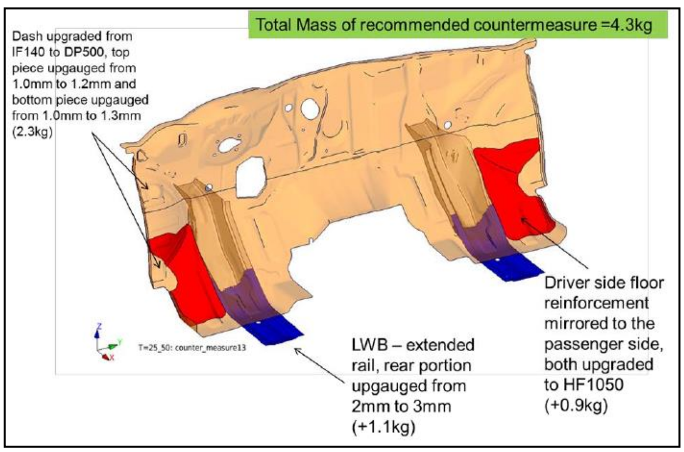


Figure 3. Structural Countermeasures to Reduce Occupant Compartment Intrusions.

The recommended changes are shown in Figure 3. These countermeasures added up to an additional mass increase of 4.3 kg for the entire body structure. These changes are given as follows:

1. The dash panel was changed to a laser-welded blank stamping, with increase in thickness from 1.00 mm to 1.20 mm upper segment and to 1.3 mm lower segment, incurring a mass penalty of 2.3 kg. Its material steel grade was also changed from low-strength steel to higher strength duel phase DP500. The dash panel using the higher grade can be successfully formed. The DP500 grade is a good formable grade with over 20 percent elongation.
2. The front rail extensions (left and right) stamped parts that were positioned under the lower dash panel and front floor panels were converted into laser-welded blank (LWB) stampings with two thicknesses. The

thickness of the rear of this part was increased from 2.00mm to 3.00mm, incurring a mass penalty of 1.1 kg for both parts.

3. The driver side front floor reinforcement panel (shown in red in Figure 3) was duplicated (mirror image) on to the passenger at an additional mass of 0.90 kg. The grade of steel was also changed to advance high-strength steel HF1050/1500 suitable only for hot-stamping.

Figure 4 shows the comparison of the dash panel before countermeasure (Baseline) and after countermeasure (CM). It can be observed that the countermeasure significantly reduced the intrusion levels of the dash below 150mm (>150mm intrusion is shown in red).

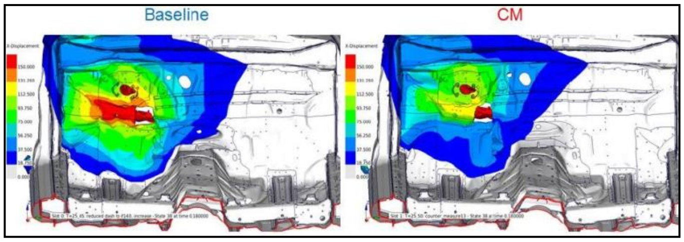


Figure 4. Baseline vs Countermeasure CAE - Dash View.

The countermeasure implementation affected little on the assembly process but significantly on the manufacturing process. Therefore, the manufacturing cost changes were estimated. The manufacturing costs of baseline parts and the corresponding countermeasure parts were calculated using the EDAG's TCM-based cost model mentioned in the introduction section. Incremental manufacturing and assembly costs of the added/subtracted components are summarized in Table 1 and Table 2. The cost of baseline parts weighing 14.73kg was estimated as $35.54 and the cost of countermeasure parts weighing 19.0kg was estimated as $59.91. The total cost increase for the countermeasures is $24.37 ($59.91 - $35.54). Total mass increase for the countermeasures is 4.3 kg (19.0 kg – 14.7 kg).

Table 1. 2014 Honda Accord Baseline Model - Subtracted Parts.

2014 Honda Accord - Baseline Parts						
Item #	Part Name	Qty per Veh	Steel Grade	Mass (kg)	Manufacturing Process	Part Piece Cost
1	Dash Panel	1	Mild 140/270	8.300	Stamping Single Thickness	$14.64
2	Dash Panel Bracket Lh	1	DP 500/800	0.900	Stamping Single Thickness	$3.68
3	Reinforcement Dash Panel Longitudinal Lh	1	Mild 140/270	2.765	Stamping Single Thickness	$8.61
4	Reinforcement Dash Panel Longitudinal Rh	1	Mild 140/270	2.765	Stamping Single Thickness	$8.61
			Total Mass	**14.73**	Total Part Piece Cost	**$35.54**

Table 2. 2014 Honda Accord Countermeasure Model - Added Parts.

2014 Honda Accord - Counter-Measure Parts						
Item #	Part Name	Qty per Veh	Steel Grade	Mass (kg)	Manufacturing Process	Part Piece Cost
1	Dash Panel	1	DP 500/800	10.600	Laser Welded Blank	$26.76
2	Dash Panel Bracket Lh	1	HF 1050/1500	0.900	Hot Stamped Single Thickness	$5.66
3	Dash Panel Bracket Rh	1	HF 1050/1500	0.900	Hot Stamped Single Thickness	$5.66
4	Reinforcement Dash Panel Longitudinal Lh	1	DP 500/800	3.300	Laser Welded Blank	$10.15
5	Reinforcement Dash Panel Longitudinal Rh	1	DP 500/800	3.300	Laser Welded Blank	$10.15
	Additional Assembly Cost					$1.53
			Total Mass	**19.000**	Total Part Piece Cost	**$59.91**

Light-Duty Pickup Truck – 2014 Chevrolet Silverado 1500

A very detailed FE model of the 2014 Chevrolet Silverado 1500 shown in Figure 5 was developed and correlated for NHTSA's lightweighting study [3]

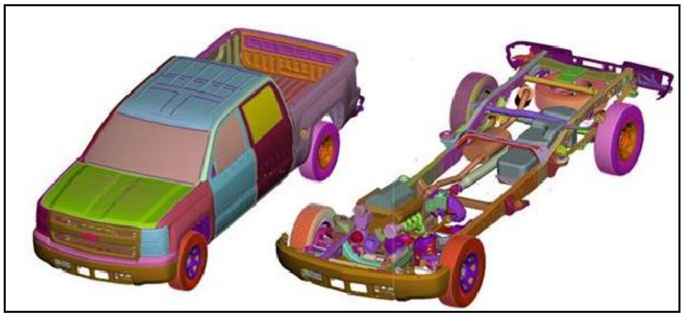


Figure 5. 2014 Chevrolet Silverado 1500 CAE Model.

For this study, the FE model was further modified from four-wheel-drive (4WD) to rear-wheel–drive (RWD) to represent the power train similar to NHTSA oblique-tested vehicles. The front drive differential, front drive shafts and power transfer unit were removed from the FE model as shown in Figure 6.

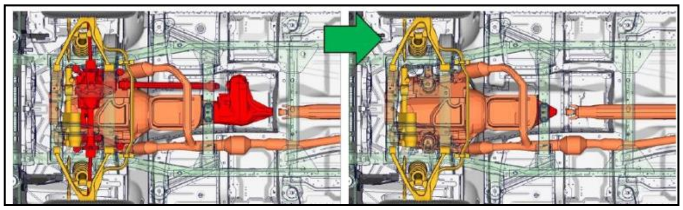


Figure 6. 2014 Chevrolet Silverado 1500 with the Front Wheel Drive Components Shown in Red.

For clarification a comparison of the tested vehicle and the updated FE model is shown Table 3.

Table 3. Oblique Test Vehicle Versus CAE Model.

Description	Tahoe (Test)	Silverado 1500 (Test)	CAE Model Silverado 1500
Model Year	2016	2012	2014
Drive	RWD	RWD	RWD
Engine Size (L)	5.3	4.8	5.3
Tested Weight (kg)	2722	2624	2582
Body Style	SUV	Crew-Cab	Crew-Cab

The FE model was correlated with the following crash load cases prior to using it for countermeasure study for the Oblique Impact:

1. NHTSA Oblique Offset Test (simulating left-side frontal oblique offset)
2. IIHS Small (25%) Overlap Front Test. Similarly, the correlated FE model was used to identify suitable countermeasures design to reduce the occupant compartment intrusions. The countermeasures were based on observed structure deformations when subjected to IIHS small offset and NHTSA oblique impact tests on the driver and passenger sides.

Higher intrusion values were observed mainly in the mid to lower section of the dash panel. The mid dash to lower area was impacted by the left front wheel and transmission on the passenger side. The rearward front wheel base intrusions were reduced by adding additional structure to the frame structure which is shown in red in Figure 7.

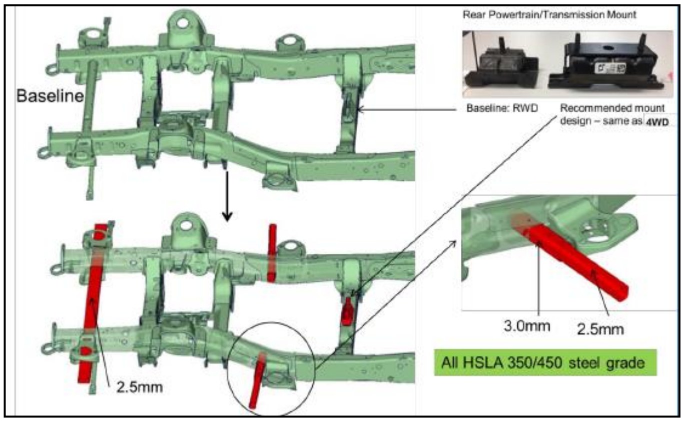


Figure 7. Structural Countermeasures to Reduce Occupant Compartment Intrusions.

Higher deformations were also observed for the IIHS small overlap results as shown in the intrusion chart in Figure 8. The developed countermeasures reduced the intrusion values for both load cases but slightly higher intrusions were found for the IIHS small overlap impact. However, the countermeasures improved the intrusions level within the acceptable range. Therefore, the developed countermeasures were decided still as a successful implementation. The countermeasure changes are shown in Figure 7. It increased the parts weight up to 9.0kg. These changes are symmetrical on the left and right sides of the vehicle. These changes are given as follows:

1. Modified front cross member to extend beyond frame rails, to be positioned in front of the front wheel/tires
2. Front wheel blocker bar positioned in front of the cab front mount
3. Change of the rear powertrain/transmission mount to the more robust design used on the 4WD Chevrolet Silverado 1500. It should be note that the 4WD mount is 1.0 kg heavier than the baseline.

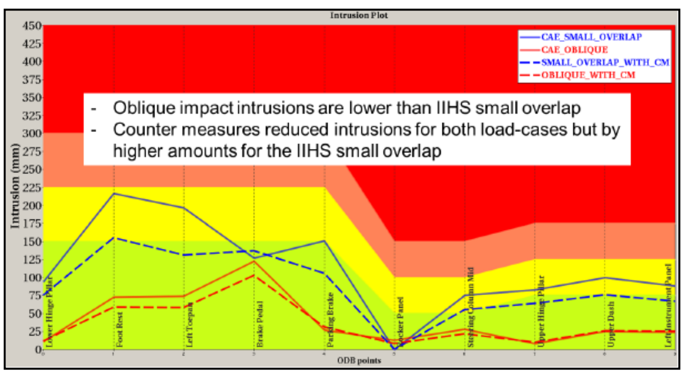


Figure 8. Structural Countermeasures: Reduce Occupant Compartment Intrusions for Oblique and IIHS Small Overlap.

Similar to 2014 Honda Accord, the manufacturing costs were estimated for Chevrolet Silverado 1500. In this case, the countermeasure implementation affected both manufacturing and assembly process. Therefore, both manufacturing and assembly costs of baseline parts and the corresponding countermeasure parts were calculated using EDAG's TCM-based cost model. Incremental manufacturing and assembly costs of the added/subtracted components are summarized in Table 4 to Table 7. From these tables, it can be noted that the total cost increase for the countermeasures is $17.35, total mass increase for the countermeasures is 9.0 kg and the cost impact is $1.93 per kilogram increase of weight.

Table 4. 2014 Chevrolet Silverado Baseline Model - Subtracted Parts.

Silverado Chassis Frame Baseline Manufacturing Costs						
Item #	Part Name	Qty per Veh	Material	Mass (kg)	Manufacturing Process	Part Piece Cost
1	Tube Front Crossmember	1	Mild 140/270	3.29	Hydoform Single Thickness	$5.08
2	Transmission Rear Mount	1	Various	0.65	Various	$2.77
			Total Mass	**3.94**	Total Parts Cost	**$7.85**

Table 5. 2014 Chevrolet Silverado Countermeasure Model - Added Parts.

Silverado Chassis Frame Countermeasures Manufacturing Costs						
Item #	Part Name	Qty per Veh	Material	Mass (kg)	Manufacturing Process	Part Piece Cost
1	Tube Front Crossmember	1	HLSA 350/450	6.50	Roll Form Closed Profile	$7.40
2	Side Frame Tube Inner Upper	2	HLSA 350/450	1.00	Roll Form Open Profile	$1.82
3	Side Frame Tube Inner Lower	2	HLSA 350/450	1.20	Roll Form Open Profile	$2.14
4	Side Frame Tube Outer	2	HLSA 350/450	2.60	Roll Form Closed Profile	$6.08
5	Transmission Rear Mount	1	Various	1.66	Various	$8.12
			Total Mass	**12.96**	Total Part Cost	**$25.56**

Table 6. 2014 Chevrolet Silverado Countermeasure Model - Assembly Cost.

Silverado Chassis Frame Baseline and Countermeasure Assembly Costs				
Item #	Part Name	Number of Fasteners or MIG Weld Length (mm)	Assembly Process	Cost
1	Chassis Frame Baseline	600 mm	MIG Weld	-$0.98
2	Chassis Frame Assembly Counter-Measure	1400 mm (additional assembly steps and fixtures cost)	MIG Weld	$3.78
		4 (washers, step bolts and nuts)	Mechanical Fasteners	$1.86
		Chassis Frame Assembly Cost Increase for the additional Countermeasures		**$4.66**

Table 7. 2014 Chevrolet Silverado Countermeasure Model - Summary Cost and Mass Increase.

Silverado Chassis Frame Baseline Versus. Countermeasure Costs				
Item #	Part Name	Process	Cost	Mass (kg)
1	Chassis Frame (Baseline)	Manufacture	-$7.85	3.94
		Assembly	-$0.98	
		Total	-$8.83	
2	Chassis Frame (Counter-Measure)	Manufacture	$20.54	12.96
		Assembly	$5.64	
		Total	$26.18	
		Δ Cost / Mass	**$17.35**	**9.02**

CONCLUSIONS

The 2014 Honda Accord and 2014 Chevrolet Silverado were chosen to conduct countermeasure implementation for NHTSA's oblique offset frontal impact. Both the vehicle has "good" to "acceptable" rating in IIHS small overlap test and "good" rating in IIHS Moderate overlap test. The FE models for both vehicles were correlated to selected crash load cases. CAE based structural modifications were implemented as countermeasures for oblique offset frontal impact targets. The intrusion levels were achieved within 150 mm target for 2014 Honda Accord and within acceptable range for 2014 Chevrolet Silverado 1500. Also, in case of 2014 Chevrolet Silverado, structural deformation was higher in IIHS small overlap compared to NHTSA's oblique offset frontal impact test. In order to reduce the structural deformation of the 2014 Honda Accord, the structural countermeasures caused 4.3kg of mass increase which in turn increased the cost by $24.37. Whereas, for 2014 Chevrolet Silverado 1500, the countermeasures required 9kg of mass increase and a cost increase of $17.35.

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REFERENCES

[1] Singh, H., Kabeer, B., Jansohn, W., Davies, J., Kan, C.-D., Kramer, D., et al. (2012). Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025. NHTSA.

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